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(21) Application Nos. 46736/70 (22) Filed 1 Oct. 1970 (19)
4059/71 5 Feb. 1971

(23) Complete Specification filed 29 Sept. 1971

(44) Complete Specification published 3 Jan. 1974

(51) International Classification F03B 3/10 F16D 23/02 F02C 3/12
F04D 13/06 13/16 25/06

(52) Index at acceptance
F1C 2D D2E
F1G 18 5C3X 5CX 8
F1T H4 H5B
F2C 1A11A3 1A7B 1A9 1D11B3 1D11G2 1D7B
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(54) ELECTRICAL POWER GENERATING PLANT

(71) We, S.S.S. PATENTS LIMITED, a British Company, of 51—55, Stirling Road, Acton Town, London, W.3, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to electrical power generating plant of the type that includes a unidirectional motor/generator, a unidirectional turbine for driving the motor/generator, and a unidirectional pump or compressor. Pumped storage plant of this type includes a hydraulic turbine and a pump, and has two principal modes of operation, namely a generating mode during which the motor/generator acting as a generator is driven by the hydraulic turbine, the pump being inoperative, and a pumping mode during which the pump is driven by the motor/generator, the hydraulic turbine being inoperative. During operation in the pumping mode the pump raises water to an elevated reservoir, and during operation in the generating mode water from the reservoir is used to drive the hydraulic turbine. Air storage plant of the said type includes a gas turbine and a compressor, and also has two principal modes of operation, namely a compressing mode during which the compressor is driven by the motor/generator acting as a motor, the gas turbine being inoperative, and a generating mode during which the motor/generator is driven by the gas turbine, the compressor being inoperative. During operation of the plant in the compressing mode the compressor delivers compressed air to a reservoir, and during peak load periods when operation of the plant in the generating mode is required air from the reservoir is mixed with fuel, burnt and expanded through the gas turbine, which drives the motor/generator.

It is an object of the invention to provide plant of the type referred to above having the advantage, as compared with known plant of the said type, of requiring shorter periods of time for change-over between the generating mode and the pumping or compressing mode.

In accordance with the invention there is provided between the shaft of the motor/generator and the shaft of the pump or compressor a toothed clutch the clutch teeth of which interengage automatically when the shaft of the motor/generator tends to rotate in the direction opposite to its normal direction relative to the shaft of the pump or compressor, or when the shaft of the pump or compressor tends to rotate in its normal direction of rotation relative to the shaft of the motor/generator, in clutch being provided with means which can be operated when required to prevent disengagement of the interengaged clutch teeth, and wherein means are provided which are operable when required to produce relative rotation between the shaft of the motor/generator and the shaft of the pump or compressor in the direction for effecting interengagement of the clutch teeth.

Embodiments of the invention are illustrated in the accompanying drawings, in which:

Fig. 1 is a diagrammatic view in side elevation of pumped storage plant in accordance with the invention,

Fig. 2 is a half sectional view, on a larger scale than Fig. 1, of a synchronous clutch incorporated in the plant illustrated in Fig. 1, the clutch being shown in a disengaged condition,

Fig. 3 is a view similar to Fig. 2 but showing the clutch in an engaged condition, and

Fig. 4 is a diagrammatic view in side ele-

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vation of air storage plant in accordance with the invention.

Referring to Fig. 1, the pumped storage plant illustrated includes a unidirectional hydraulic turbine 1, a unidirectional motor/generator 2 and a unidirectional pump 3. The shaft of the turbine 1 is drivably connected to one end of the shaft of the motor/generator 2 through a first synchronous self-shifting toothed clutch 4, the clutch teeth of which interengage automatically when the turbine 1 tends to overrun the motor/generator 2 in the normal direction of rotation and disengage automatically when the motor/generator 2 overruns the turbine 1. The other end of the shaft of the motor/generator 2 is drivably connected to the shaft of the pump 3 through a second synchronous self-shifting toothed clutch 5 which overruns when the motor/generator 2 rotates relatively to the pump 3 in the normal direction of rotation of the motor/generator 2 and engages when the motor/generator 2 tends to rotate relatively to the pump 3 in the reverse direction of rotation of the motor/generator. The clutch 5 is shown in detail in Figs. 2 and 3.

The clutch 5 engages whenever the pump 3 (Fig. 1) tends to overrun the motor/generator 2 in the normal direction of rotation, and when engaged it is required to transmit torque from the motor/generator 2 to the pump 3.

The clutch 5 is shown in detail in Figs. 2 and 3. It includes a first clutch part 30 formed with a ring of internal locking teeth 31 and carrying a clutch ring 32 which is formed with a ring of internal clutch teeth 33 and which carries pawls 34 which coact with ratchet teeth 35 on an intermediate member 36. The member 36 is formed with a ring of external clutch teeth 37, and with internal helical splines 38 engaged with external helical splines 39 formed on a second clutch part 40. The clutch part 40 carries a ring 41 formed with straight splines 42 engaged with straight splines 43 in a part 44 of a locking sleeve 44, 45, 46, 47, 48, the part 44 being formed with a ring of external locking teeth 49. The part 48 of the locking sleeve is formed with a ring of internal baulking teeth 50, and the second clutch part 40 carries with slight radial clearance a baulking ring 57 with external baulking teeth 51. The baulking ring 57 also has internal teeth 58 which slidably engage with external teeth 59 on intermediate member 36. The parts 44, 45 and 46 of the locking sleeve are shaped to form a hydraulic cylinder which is axially movable relative to a piston 52 carried by the clutch part 40, ducts 53, 54 and 55 being provided for the supply of oil under pressure to the cylinder as shown by the arrows, the cylinder and piston serving as a hydraulic ram operable when appropriate to shift the locking sleeve 44—48 into toothed engagement with the first clutch part 30. Oil is also supplied to the synchronous clutch, as indicated by the arrows. A servo mechanism (not shown) acting on a fork 56 is used to effect initial interengagement of the locking teeth 31 and 49, the clutch engaging movement being completed by supplying oil under pressure to the hydraulic ram.

The operation of the clutch 5 is as follows. Assuming that the clutch 5 is in the disengaged condition shown in Fig. 2, and that the machinery is stationary, operation of the servo mechanism in an attempt to shift the locking sleeve 44—48 into toothed interengagement with the first clutch part 30 will cause the baulking teeth 50 to come into end contact with the baulking teeth 51. Movement of the locking sleeve 44—48 is thereby prevented. When the clutch part 30 rotates relative to the clutch part 40 in the direction opposite to its normal direction pawls 34 engage ratchet teeth 35, whereupon further rotation of the clutch part 30 causes the intermediate member 36 to move in the direction for interengagement of the clutch teeth 33 and 37. Sufficient backlash is provided between the teeth 58 and the external teeth 59 to prevent overloading of the pawls 34. As the ratchet teeth 35 pass axially out of engagement with the pawls 34, and the clutch teeth 33 and 37 come into flank contact, the backlash between teeth 58 and 59 reduces to zero, and further travel of the intermediate member 36 therefore rotates the baulking ring 57 relative to the clutch part 40 so that the baulking teeth 50 and 51 are aligned for interengagement and the locking teeth 31 and 49 are also aligned for interengagement. The servo mechanism can therefore shift the locking sleeve 44—48 to bring the external teeth 49 into initial interengagement with the internal teeth 31, this movement being sufficient to bring the piston 52 to the part of the cylinder with close clearance. Movement of the intermediate member 44—48 into full toothed engagement is effected by supplying oil under pressure to the hydraulic ram, by which the locking teeth 31 and 49 are brought into the fully interengaged condition as shown in Fig. 3 and the sliding surfaces of fork 56 are unloaded.

If now the clutch part 30 is rotated relative to the clutch part 40 in the normal direction the reversal of torque in the clutch 5 causes the locking teeth 31 to move into flank contact with external teeth 49 and also causes the clutch teeth 33 and 37 to take up angular relative positions in which they are unloaded. Torque is now transmitted from the clutch part 30 to the clutch part 40 through the locking teeth 31 and 49 and the straight splines 42 and 43.

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To disengage the clutch 5 it is first necessary to cause a reversal of the torque therein to unload the locking teeth 31 and 49 and allow them to be shifted out of interengagement by the servo mechanism. This torque reversal is brought about by reducing the rotational speed of the main clutch part 30 relative to the main clutch part 44—48 in the normal direction or rotating clutch part 30 backwards relative to clutch part 40. The supply of oil under pressure to the hydraulic ram is then shut off and the servo mechanism is operated to shift the locking sleeve 44—48 to the fully disengaged position shown in Fig. 2.

Reverting to Fig. 1, the operation of the pumped storage plant is as follows, starting from the standstill condition of the plant with the clutches 4 and 5 disengaged. Water is admitted to the turbine 1 to drive it in the normal direction, the rotation of the turbine shaft relative to the shaft of the motor/generator 2 causing the clutch 4 to engage so that the motor/generator 2 is brought up to full speed rapidly by the power of the turbine in the normal direction of rotation for synchronising and connection to the grid for the generation of electrical power. If at this stage it is desired to change over to synchronous condensing operation by the motor/generator the turbine 1 is shut down, whereupon the clutch 4 automatically disengages so that the motor/generator 2 continues to rotate. During these operations the storage pump 3 remains at standstill since the unlocked clutch 5 overruns.

To change over from generating to pumping, the turbine 1 if running is shut down and the motor/generator 2 is disconnected from the grid, the retarding of the rotating machinery being assisted by an electrical braking system having the characteristic that when the motor/generator 2 comes to rest there will be an immediate reversal of the rotation of the shaft of the motor/generator relative to the stationary shaft of the storage pump 3, causing the synchronous clutch 5 to engage whereupon it is locked to connect the motor/generator 2 bidirectionally to the pump 3.

When the storage pump 3 has been clutched bidirectionally to the motor/generator 2, water is admitted to the turbine 1 to bring the turbine up to full operating speed together with the motor/generator 2 and the storage pump 3. The motor/generator is thereupon electrically synchronised with the grid for operation as a motor. The turbine 1 is then shut down, with the effect that the clutch 4 disengages and the motor/generator 2 continues to run and drives the storage pump 3 through the engaged and locked clutch 5.

To change over from the pumping mode to the generating mode the delivery valve of the pump 3 is closed and the motor/generator 2 is disconnected from the grid, whereupon rapid retardation of the rotating machines take place. When the torque between the shafts of the motor/generator 2 and the storage pump 3 reverses under the action of the electrical braking system the servo mechanism associated with the clutch 5 is actuated to urge the locking sleeve 44—48 to the disengaged condition, and when it is disengaged water is admitted to the turbine 1, whereupon the clutch 4 engages automatically at synchronism and the turbine 1 drives the motor/generator 2, and clutch 5 disengages. The turbine 1 then accelerates the motor/generator up to full speed for electrically synchronising with the grid and for the generation of electrical power. Since the clutch 5 is disengaged the motor/generator 2 overruns the storage pump 3, which remains stationary.

When changing over from the generating mode to the pumping mode water braking of the turbine 1 may be used in addition to or instead of electrical braking of the motor/generator and for effecting reversal of the shaft of the motor/generator 2 to engage the clutch 5 which is then locked to connect the motor/generator to the storage pump. If water braking is to be used, the clutch 4 will need to be provided with a locking means, known in itself, such that when the turbine 1 is rotating at full speed together with the motor/generator 2 it can be clutched bidirectionally to the motor/generator by locking the clutch 4 in engagement. The turbine is then shut down and the motor/generator 2 is disconnected from the grid, the rate of retardation of the turbine 1 and the motor/generator 2 being regulated by the controlled admission of braking water to the turbine 1. Upon coming to rest the reversal of rotation of the shaft of the motor/generator 2 needed to enable the clutch 5 to engage is effected by reversal of the rotation of the turbine and motor/generator under the influence of the braking water, which is then shut off.

An alternative means of engaging the clutch 5 for locking the motor/generator 2 bidirectionally to the storage pump 3 for operation in the pumping mode is to rotate the shaft of the storage pump 3 in the normal direction of rotation, thereby causing the clutch 5 to shift into engagement whereupon it is locked. The required rotation of the pump shaft may be achieved by the admission of water under pressure to react on the pump impeller in the sense to rotate the pump shaft in the required direction, whereupon the clutch 5 engages and is then locked so that the motor/generator 2 is connected bidirectionally to the pump 3.

Another alternative means of rotating the

shaft of the storage pump 3 in the direction for engagement of the clutch 5 is to provide a shaft turning gear which may conveniently be of known servo actuated ratchet type acting in the direction of rotation which is the normal direction of rotation of the shaft of the storage pump 3 during the pumping mode.

Referring now to Fig. 4, the air storage plant illustrated includes a gas turbine 1^1, a motor/generator 2^1 and a compressor 3^1. The shaft of the gas turbine 1^1 is connected to the shaft of the motor/generator 2^1 through a synchronous self-shifting clutch 4^1 which is of the same construction as the clutch 4 described above. The shaft of the motor/generator 2^1 is connected to the shaft of the air compressor 3^1 through a clutch 5^1 which is of the same construction as the clutch 5 described above. The plant also includes an auxiliary motor 60 the shaft of which is drivably connected to the shaft of the compressor 3^1 through a synchronous self-shifting clutch 61 which is arranged to engage automatically when the shaft of the auxiliary motor 60 tends to rotate relatively to the shaft of the compressor in the normal direction of rotation, and to disengage automatically when the compressor 3^1 overruns the motor 60. The auxiliary motor 60 is of low power, e.g. 15% of the power required to drive the compressor 3^1 at full speed.

The operation of the air storage plant is as follows, starting from the standstill condition of the plant with all three clutches disengaged.

The auxiliary motor 60 is switched on, and its rotation causes the clutch 61 to engage whereby the compressor is driven by the motor 60 which has a maximum speed of say 1500 rpm. The rotation of the compressor shaft relative to the shaft of the motor/generator 2^1 causes the clutch 5^1 to engage whereupon it is locked to connect the motor/generator 2^1 bidirectionally to the compressor, so that the motor/generator 2^1 is driven by the auxiliary motor 60 and attains a speed of 1500 r.p.m.

When the plant is required to continue to operate in the compressing mode the gas turbine 1^1 is started up, making use in the combustion chamber of air from the compressor 3^1, which air is now being delivered in sufficiently large quantity by the compressor 3^1. When the speed of the turbine 1^1 is such that it tends to overrun the motor/generator 2^1 the synchronous clutch 4^1 engages, and when the speed of the motor/generator 2^1 and of the compressor clutched thereto by the clutch 5^1 exceeds the speed of the auxiliary motor 60 the clutch 61 disengages and the auxiliary motor 60 can be switched off. The turbine continues to accelerate up to a speed of say 3000 r.p.m. and the motor/generator 2^1 and the compressor 3^1 are also accelerated to this speed by reason of the clutches 4^1 and 5^1 being engaged. When this speed has been attained the motor/generator 2^1 is connected to the grid to act as a motor, and the gas turbine 1^1 is shut down, whereupon the clutch 4^1 disengages and overruns. The motor/generator 2^1 continues to rotate at 3000 r.p.m. and drives the compressor 3^1 through the engaged clutch 5^1, the air supplied by the compressor 3^1 being used to fully charge the reservoir.

To change over from the compressing mode to the generating mode the motor/generator 2^1 is disconnected from the grid and the auxiliary motor 60 is switched on, rapidly accelerating to 1500 r.p.m. When the speed of the motor/generator 2^1 and of the compressor 3^1 tends to fall below 1500 r.p.m. the clutch 61 engages and the auxiliary motor 60 begins to drive the compressor 3^1 and motor/generator 2^1. The lock of clutch 5^1 is thereby unloaded and is unlocked but the clutch 5^1 remains engaged since the compressor 3^1 is driving the motor/generator. The gas turbine 1^1 is then started up, using air from the reservoir, and when the speed of the turbine exceeds the speed of the motor/generator, viz. 1500 r.p.m., the clutch 4^1 engages so that the motor/generator 2^1 is driven by the gas turbine 1^1, the clutch 5^1 disengaging. The auxiliary motor 60 is then switched off and comes to rest, and the compressor 3^1 also comes to rest. When the turbine 1^1 has attained a speed of 3000 r.p.m. the motor/generator 2^1 is reconnected to the grid to act as a generator when driven by the gas turbine 1^1.

To change over from the generating mode to the compressing mode the auxiliary motor 60 is switched on and accelerates the compressor to 1500 r.p.m. The motor/generator 2^1 is then disconnected from the grid and the power of the gas turbine 1^1 is reduced so that the motor/generator 2^1 and the gas turbine 1^1 decelerate. When the speed of the motor/generator falls to 1500 r.p.m. the clutch 5^1 engages and is thereupon locked. The power of the gas turbine 1^1 is then increased to accelerate the motor/generator 2^1 to 3000 r.p.m. for reconnection to the grid. The gas turbine 1^1 is shut down, and the clutch 4^1 disengages. The motor/generator 2^1 continues to drive the compressor 3^1.

WHAT WE CLAIM IS:—

1. Electrical power generating plant comprising a unidirectional motor/generator, a unidirectional turbine for driving the motor/generator, and a unidirectional pump or compressor, wherein there is provided between the shaft of the motor/generator

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2. Electrical power generating plant according to claim 1, wherein the means for producing relative rotation between the shaft of the motor/generator and the shaft of the pump or compressor are adapted to effect electrical braking of the shaft of the motor/generator and have the characteristic that the shaft of the motor/generator when stopped by said braking means is then reversed in rotation sufficiently to interengage the clutch teeth.

3. Electrical power generating plant according to claim 2, wherein the turbine is a hydraulic turbine, a lockable clutch is provided between the shaft of the turbine and the shaft of the motor/generator, and means are provided for effecting water braking of the shaft of the hydraulic turbine, instead of or in addition to the means for effecting electrical braking of the shaft of the motor/generator, to effect or assist reversal of rotation of the shaft of the motor/generator to interengage the clutch teeth of the clutch between the shaft of the motor/generator and the shaft of the pump or compressor.

4. Electrical power generating plant according to claim 1, wherein the means for producing relative rotation between the shaft of the motor/generator and the shaft of the pump or compressor are operable to effect the admission of working fluid to the pump or compressor to rotate it in its normal direction of rotation.

5. Electrical power generating plant according to claim 1, wherein the means for producing relative rotation between the shaft of the motor/generator and the shaft of the pump or compressor include a motor operable to rotate the shaft of the pump or compressor in its normal direction of rotation.

6. Electrical power generating plant substantially as hereinbefore described with reference to Figs. 1 to 3 or to Fig. 4 of the accompanying drawings.

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Printed for Her Majesty's Stationery Office by Burgess & Son (Abingdon), Ltd.—1974.
Published at The Patent Office, 25 Southampton Buildings, London WC2A 1AY
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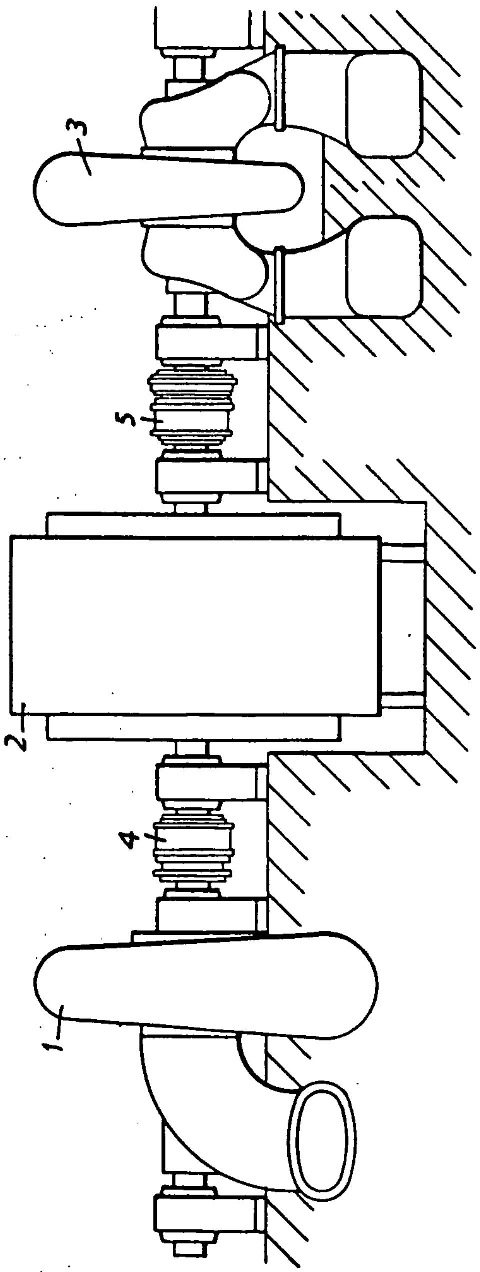
FIG. 1.



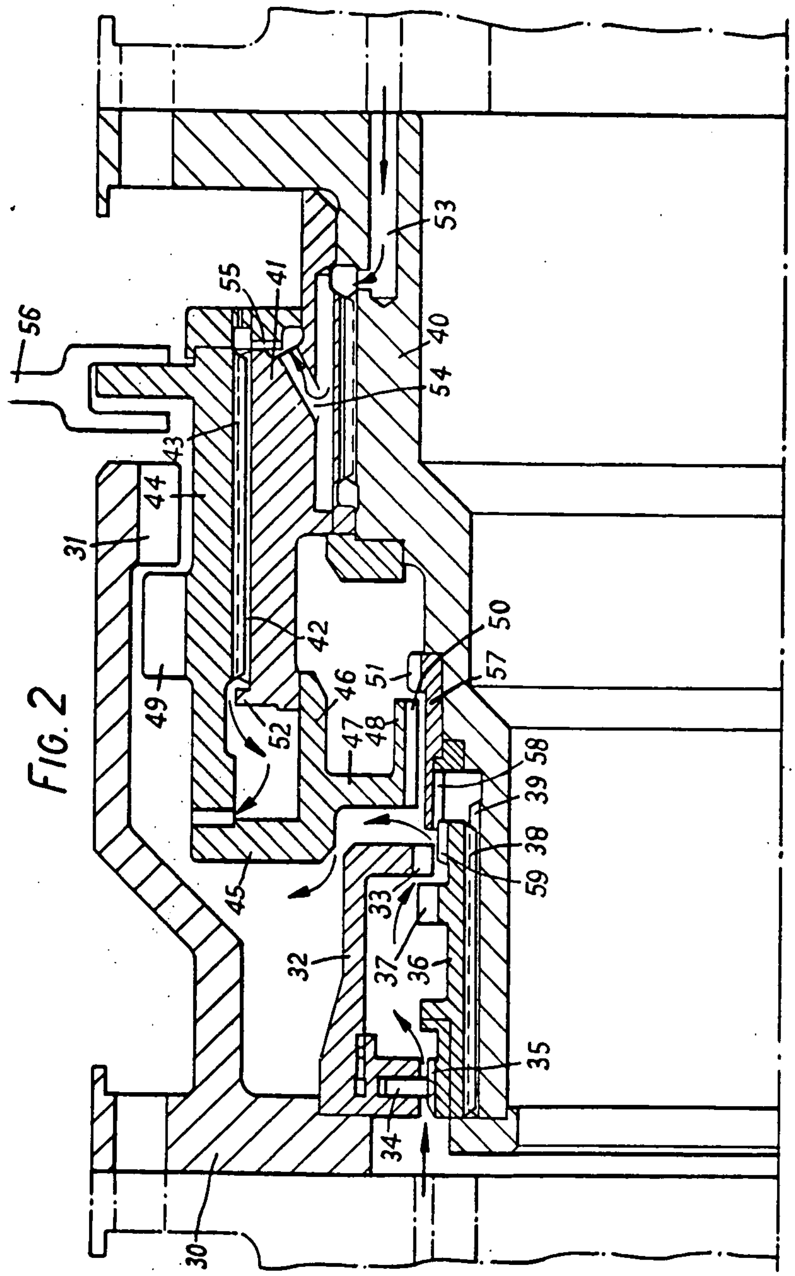

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FIG. 2

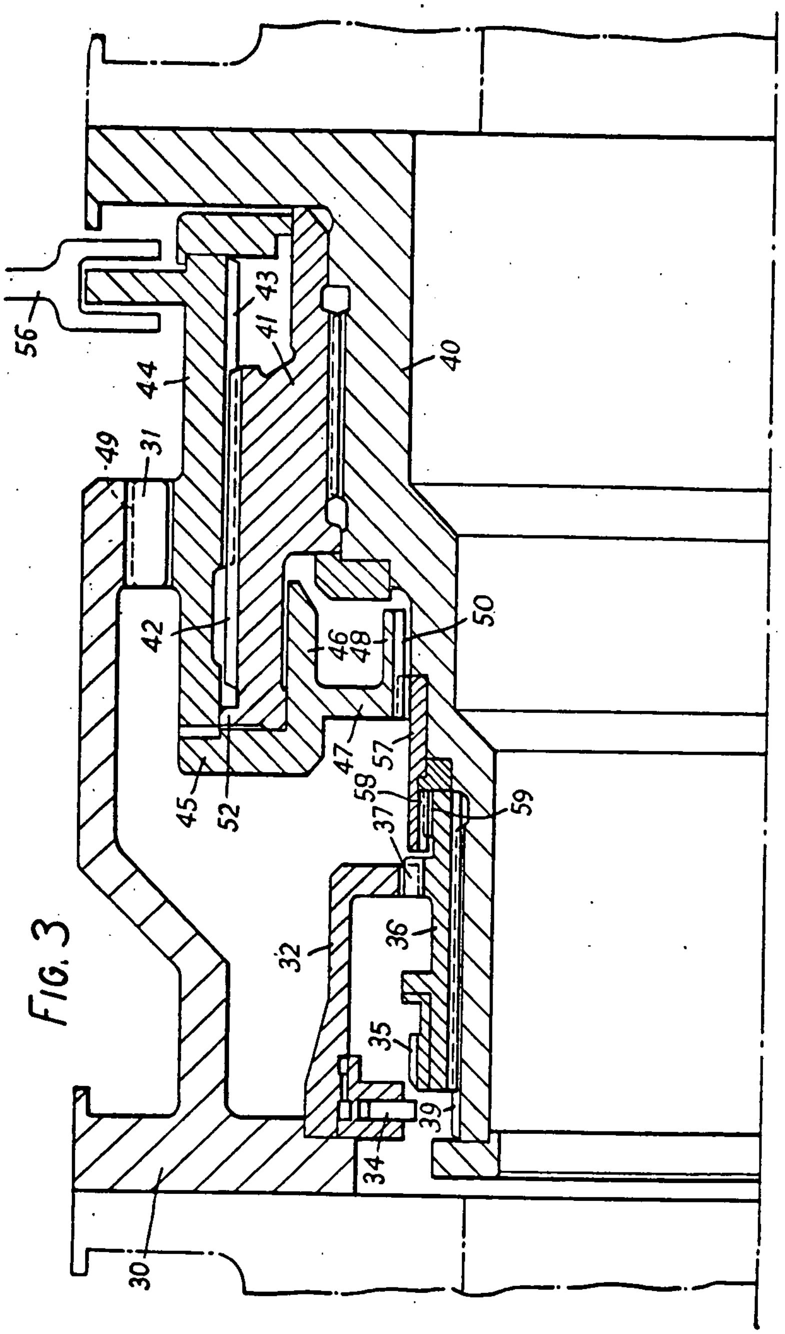

FIG. 3

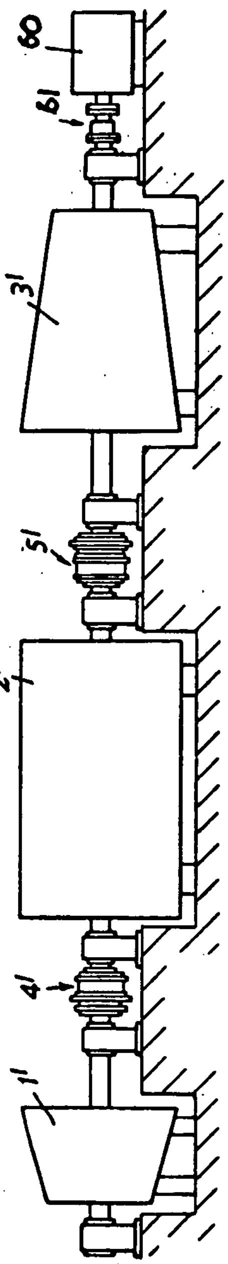

FIG. 4.

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